Supplement to

STRESSES INDUCED IN A SANDWICH PANEL BY LOAD APPLIED AT AN INSERT

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Supplement to

STRESSES INDUCED IN A SANDWICH PANEL BY LOAD APPLIED AT AN INSERT[1]

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Summary

A previous study has indicated that theoretical formulas for the stresses produced in sandwich panels by a loaded insert are satisfactory for use in the design of sandwiches having isotropic solid-type cores. This report presents the results of tests using panels having honeycomb-type cores. The results show a good correlation between computed and measured values, and indicate that the theoretical formulas for isotropic cores can also be used for the design of load-carrying fittings in panels having orthotropic honeycomb-type cores.

Introduction

This report supplements the previous work dealing with the general problem of the design of load-carrying fittings in sandwich panels reported in Forest Products Laboratory Report No. 1845. The previous experimental work was limited by the procedures used to tests of circular sandwich panels having isotropic solid-type cores of end-grain balsa or cork board. The present study utilizes a different method for determining shear strains in the sandwich cores, and reports the results of tests of sandwich panels having orthotropic cores of aluminum honeycomb.

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Experimental Procedure

Sandwich panels were fabricated, and shear specimens and circular panels were cut from them for testing. Each circular panel was tested by loading through an aluminum insert. The differential movement under load of the top and bottom facings at various distances from the edge of the insert was measured by Tuckerman gages. The method used for correcting these Tuckerman readings to shear strains as measured on matched shear specimens is outlined in the appendix to this report.

Strains were measured on the facings of some of the panels by means of SR-4 resistance-wire strain gages.

Materials Tested

Nine test panels, as described in table 1, were fabricated for test. The commercial honeycomb-core material consisted of 0.003-inch perforated aluminum foil formed into 1/4-inch cells of hexagonal shape.

The construction of the core material and the orientation of the planes involved in this study are illustrated in figure 1. The facings were of 75ST clad aluminum alloy, and the aluminum inserts used were turned from solid bar stock.

Fabrication of Test Panels

The test panels were fabricated as 24-inch square specimens as shown in figure 2. This permitted close matching between the 20-inch diameter test panel and the shear specimens that were cut from the remaining portion of each panel.

The core material was cut to the required thickness with a bandsaw, and the resulting sections were lightly glued together in proper orientation to form mats 24 inches square. A 2-inch diameter solid aluminum insert was carefully machined to the same thickness as the core and inserted in the center of each mat. One-quarter inch diameter holes in both the insert and the facings permitted accurate alignment of core and facings. The facings were glued to the cores with a formulation of epoxy resins.

The circular panels and shear specimens were cut to required size with a metal-cutting bandsaw.

To permit the measurement of the differential movement of the upper and lower facings of the panels, holes were drilled at the locations shown in figure 2. These holes were 1/4 inch in diameter and penetrated the top facing and core. A concentric 1/16-inch diameter hole was drilled through the bottom facing for a thin bolt which extended above the top facing (fig. 4).

Method of Test

The method used for testing the panels is illustrated in figure 3. The 20-inch diameter panels were accurately centered over an 18-inch diameter hole in a heavy base of densified laminated wood mounted on the upper platen of a testing machine. In all cases, the test panels were simply supported and not clamped to the base block. A tensile load was transmitted to the panel insert through a flexible cable attached to the lower head of the testing machine. This method of loading permitted the unrestricted use of the Tuckerman gages at any point on the upper portion of the panel.

Of major interest in this study is the distribution and magnitude of core shear stresses at various locations in the panel. These stresses can be determined if the shear strains at the points in question can be measured. In the previous study, these shear strains were measured with SR-4 type gages imbedded in the core. Because of the discontinuous nature of the honeycomb core in the present study, a new method for determining shear strains was necessary. Figure 4 illustrates the method used. The method consists essentially of a means of measuring the differential movement of the top and bottom panel facings at a given point. To accomplish this, a 1/16-inch diameter bolt, extending through the center of the 1/4-inch diameter hole in the top facing, was firmly locked in place on the bottom facing, as shown. The movement of this bolt with respect to a special clip glued in place on the top facing was measured by a Tuckerman optical strain gage. A few trials indicated that the observed movement was proportional, but not equal, to the shear strain. The method used for obtaining adjusted values is outlined in detail in the appendix to this report.

Simultaneous readings of load and strain in the core at two gage locations were obtained at uniform load increments until a previously determined load, which was well within the elastic limit of the panel, was reached. This procedure was repeated until values had been obtained at all test points (fig. 3). Strains were measured in the LT and LR directions on all panels, and also in the L 45° direction on one panel of each thickness (figs. 1 and 2).

Facing strains were determined on one panel of each thickness by means of SR-4 gages of 1/4-inch gage length glued to the top facing. These tests were made prior to drilling the holes in the panel. The gages were glued on at distances of 1-1/4, 1-1/2, 2, and 3 inches from the center of the insert. Facing strains were measured in the longitudinal and radial directions, and also at 45°.

The shear tests of the specimens cut from the square panels were made in accordance with the method outlined in ASTM Designation C273-53[3] and as illustrated in figure 5.

Formulas Used

Two of the formulas presented in Report No. 1845 are used and referred to in this report. They are the formula for the shear stress in the core at radius (r)

$$\tau(r) = \frac{PI_m}{\pi(h + c)\ I} K \qquad (1)$$

in which

$$K = \frac{1}{r}\left[1 - \sqrt{r}\,\frac{\sqrt{b}\ \sinh \alpha(r - b) + \sqrt{a}\ \sinh \alpha(a - r)}{\sqrt{ab}\ \sinh \alpha(a - b)}\right] \qquad (2)$$

and the formula for the facing stress at the edge of the insert

$$\sigma_r = \frac{Ph}{\pi f(h + c)^2}\left[1 + \frac{h + c}{h(\alpha b)} - \frac{2a^2}{a^2 - b^2}\log\frac{a}{b} - \frac{3(h + c)^2}{h(h - c)(\alpha b)}\right] \qquad (3)$$

where $\tau(r)$ -- shear stress in the core at radius r
σ_r -- facing strain at radius r
P -- applied load at insert
c -- core thickness
h -- total sandwich thickness
r -- radius measured from center of insert
a -- outer radius of sandwich plate
b -- radius of insert

$$I_m = \frac{ff'\ (h + c)^2}{4(h - c)}$$

f, f' -- facing thicknesses; equal or unequal

$$I = I_m + I_f$$

$$I_f = \frac{f^3 + f'^3}{12}$$

$$\alpha = \sqrt{\frac{G(h - c)\ I}{Ecff'\ I_f}}$$

G -- shear modulus of the core, associated with core direction in which stresses are required.

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[3] American Society for Testing Materials, 1952 Standards, Part IV.

Presentation of Data

The measurements of shear stresses in the cores of the panels are tabulated in tables 2, 3, and 4. The values in columns 1 to 5 inclusive of tables 2 and 3 were obtained from tests of shear specimens cut from the outer edges of each 24-inch square panel (fig. 1). The values obtained from tests on shear specimens from the panels of 1/2-inch nominal thickness were also used in the computation of values for the 3/4-inch nominal thickness panels (table 4). Sufficient shear specimens of the required length (9 inches) could not be obtained from the thicker panels. The distance of the center of each gaging hole from the center of the panel is shown in column 7. Column 9 shows the indicated movement at each gaging hole as determined by the Tuckerman gages. The shear stress in column 10 was computed on the assumption that the entire indicated movement represented a shear strain. The values in column 11 were obtained from those in column 10 by the method outlined in the appendix. The values tabulated in column 12 were computed using formula 1, with K given by formula 2. The values of parameter K, from the adjusted test data and as computed by formula 2, are given in columns 13 and 14 respectively. The data in tables 2, 3, and 4 are presented graphically in figures 6, 7, and 8.

The measured facing strains and the computed facing strains at the edge of the insert for one panel of each thickness are tabulated in table 5 and shown graphically in figure 9.

Results of Tests

The observed and computed values of the parameter K are compared in figures 6, 7, and 8. The curves for the computed values of K in the LT and LR directions for the 1/4- and 1/2-inch nominal thickness panels are based on the average dimensions and properties of three panels of the same nominal thickness. In general, the values obtained in the LT direction are somewhat higher than the values in the LR direction. The observed values are distributed fairly uniformily above and below the computed values, and reach a maximum of about 1 near the edge of the insert. In general, the experimental points show good agreement with the computed curves.

In addition to the data presented, measurements of the relative movement of the two facings in a L 45° direction were obtained on one panel of each thickness. In nearly every instance, the values obtained were intermediate between the values in the LT and LR directions, and therefore were not presented in detail in this report.

Figure 9 shows the observed direct radial strains at various points on the top facings of one panel of each thickness, and the computed strains at the rim of the insert for each panel. For ease of comparison, the strains are shown at the arbitrarily selected center load of 100 pounds on each panel. The strains show a rapid increase as the rim of the insert is approached. The maximum values obtained at a distance 1/4 inch from the insert are well below the computed value at the actual edge of the insert. As mentioned previously, the measured strains in the LT direction are greater than those in the LR direction, with the strains in the L 45° direction being intermediate. The computed strains are greater in the LR than in the LT direction. No apparent reason for this discrepancy was noted.

As pointed out in Report No. 1845, the designer of a sandwich structure involving load-carrying fittings is interested in the maximum shear and facing stresses involved, and the points at which these stresses occur. The present study was limited to one type of core material, one panel diameter, and panels of three different thicknesses. However, the data do provide a good correlation between the experimental and computed values.

Conclusions

Report No. 1845 indicated that previously developed formulas for the determination of shear stresses in the core and facing stresses in sandwich panels having load-carrying inserts in solid-type cores are satisfactory for design purposes. The purpose of this supplementary report was to check the validity of these formulas for use in the design of load-carrying inserts in sandwich panels having honeycomb cores. Tests of nine sandwich panels, having aluminum foil honeycomb cores, aluminum faces, and solid aluminum inserts, show a good correlation between observed and calculated values. This further confirmation indicates that the formulas presented are satisfactory for design purposes.

Appendix

Report No. 1845 (and No. 1828, on which it is based) presents formulas for the determination of shear stresses in the core of a sandwich panel due to a load applied at an insert. To check these formulas experimentally, an accurate method of measuring shear strains (hence stresses) in such a panel under load is required. The experimental work reported in Report 1845 was limited to tests of panels having solid-type cores in which it was possible to read shear strains by means of SR-4 resistance-wire strain gages imbedded in the cores. To extend the experimental work to discontinuous cores of the honeycomb type, a new method of determining shear strains within the panel had to be developed.

The method selected for the measurement of core strains has been illustrated and described in the main body of this report. From a theoretical standpoint, the method is objectionable since it is necessary to drill holes in the panel facings, thus introducing stress concentrations and discontinuities. It was also necessary to disturb the core locally since the 1/4-inch drill penetrated the core to mark the center of the concentric hole in the bottom face. A few preliminary trials showed that the differential movement due to shear indicated by the Tuckerman gages was roughly twice that to be expected at any radial section of the panel. A further investigation of this method was accomplished by running a series of bending tests on rectangular sandwich strips, since the data obtained could be more readily analyzed. Figure 10 shows such a sandwich strip under test, and the diagram in table 6 indicates the placement of the applied loads.

A total of 8 specimens having 0.032-inch thick facings were tested for shearing, 4 in the LT direction and 4 in the LR direction. The specimens were cut from panels which duplicated the construction of the 1/2-inch thick panels as closely as possible. The specimens were 15 inches long and 2 inches wide, with a core thickness of 1/2 inch. The strain measuring techniques used for the circular panels were duplicated as closely as possible. Strain measurements were made on each specimen at a point 1/2 inch in from one reaction, 1/2 inch from one of the load points, at the exact center of the specimen, and at a point halfway between one of the load points and a reaction. These points are labeled 1, 2, 3, and 4, respectively, in the diagram in table 6. Thus measurements were made at 3 points of equal shear (points 1, 2, and 4) and 1 point of zero shear (point 3). The differential movement of the two facings as indicated by the Tuckerman gages are shown in table 6. Some unexpected differences do occur, but the readings at points 1, 2, and 4 are of essentially the same magnitude. Three of the specimens showed a zero movement at the central section, while the remainder of the specimens indicated a limited movement.

Eight shear specimens were also cut from the test panels and tested as previously described and as illustrated in figure 5. The results of these tests are also listed in table 6.

The adjustment factors for conversion of indicated Tuckerman readings to shear strains were determined in the following manner. The shear stress at any point between the load point and reaction of the sandwich beam (using average dimensions) was found by means of the usual sandwich formula:

$$\tau = \frac{P}{(h + c)\ b}$$

in which P = total load applied to specimen
h = total sandwich thickness
c = core thickness
b = width of sandwich

In the LT direction, this formula indicated an average shear stress of 46.5 pounds per square inch in a beam carrying a 100 pound load. When the average movement indicated by the Tuckerman gages at points 1, 2, and 4 on all four beams (0.001147 inch per inch) was considered to be entirely due to shear, the indicated shear stress in the beam (using the average modulus of rigidity of the material as determined by the shear tests, 69,675 pounds per square inch) was found to be 79.9 pounds per square inch. Thus a reduction factor of 0.582 is required to reduce this value to the computed value of 46.4 pounds per square inch. Similarly, the reduction factor in the LR direction was found to be 0.650.

It is believed that the correction factors are adequate for the purpose intended, but a few limited tests were conducted in an attempt to better understand the mechanics of the problem. Shear tests were conducted as illustrated in figure 5, using both a dial gage for indicating movement and a Tuckerman gage reading the movement of a pin extending from facing to facing of the heavy metal plates. They gave identical results, indicating that the two methods are comparable for this type of loading. Reversal of the unsupported end of the glued-on clips did not change the magnitude of the readings obtained. Readings obtained with the fixed knife edge of the Tuckerman gage resting directly on the facing and the movable knife edge on the projecting pin were almost identical to the readings obtained with the gage supported on the glued-on clip, if the separately measured facing strains adjacent to the pins were taken into account. This indicates that strain readings obtained by supporting the gage on the glued-on clip were not affected by facing strains.

A clip of special design for supporting the Tuckerman gage gave values differing 25 percent from the average when the clip was reversed in position. This special clip had sharp knife edges on one end that rested in line with the bolt that extended through the bending specimen. The other end of the gage rested on a small steel ball. The average value obtained was about equal to that obtained with the glued-on clip.

If a sandwich beam having relatively thin facings and a non-uniform core (two materials of high and low rigidity placed alternately along the length of the beam) is subjected to a bending load, the slope of the facings in sections of uniform shear will be influenced by the underlying core. The facings in the area of core with the low modulus of rigidity will assume a steeper slope than the adjacent sections. The extent that this condition holds true for a honeycomb-core sandwich with thin facings is not known. If this condition were present in a beam of such material, the method used in this study for measuring shear would be expected to indicate shear-strain values that would be too high, since no core material was present at the points of shear measurement. The effective core shear modulus would then be very low at the point of measurement, thus allowing large local strains.

The error in indicated shear strain should decrease with an increase in facing thickness. To check this probability, a few additional tests of beams having facings of different thicknesses were made. The results of these tests are also tabulated in table 6, and are shown graphically in figure 11. All of the data in table 6 were obtained under identical loads and methods of loading, thus making direct comparison possible. The additional beams tested differed only in the thickness of facings used. Figure 11 shows that there is a rather uniform decrease in indicated shear strain as the thickness of facing increases, with the 0.064-inch thick facing giving values almost equal to the theoretical shear at the point of measurement.

The data in table 6 show that the amount of deflection at the center of the span (col. 3) varies with the facing thickness, since all the beams were subjected to the same shear stress. The tests tabulated in table 7 and shown graphically in figure 12 were made to check any possible effect of this variation on the indicated shear measurements. The data in the upper portion of table 7 were obtained using progressively shorter distances between reaction and load point on the same specimen. In each case, the shear was measured at the center point between load point and reaction (location 4 of sketch in table 6). The plotted points in figure 12 indicate that the indicated shear strains remain practically uniform under the varying amount of deflection which occurred. The comparable value for specimens having 0.032- and 0.064-inch facings (from table 6) are also included in table 7 and figure 12 for comparison. The deflections, slopes, and radii of curvature values shown in columns 7, 8, and 9, respectively, were computed from the measured center deflections, and are based on theoretical values at the neutral axis of the beams rather than the actual conditions that may be present at the facings.

In conclusion, it has been shown that the method of measurement used for determining shear strains in the core of a sandwich panel is not an exact method, since the results are influenced by the facing thickness. However, reasonable values can be obtained by proper calibration techniques. The calibration factors presented in this report apply only to the particular type of material tested and identical methods of test.

Table 1.--Description of test panels. Panels were 20 inches in diameter, with a solid aluminum insert 2 inches in diameter, faces of clad aluminum 0.032 inches thick, and a honeycomb core of 0.003 inch thick foil, 1/4-inch cell size.

Panel No.	Average panel thickness	Shear modulus of core		Average parameter α	
		LT direction	LR direction	LT direction	LR direction
(1)	(2)	(3)	(4)	(5)	(6)
	Inch	P.s.i.	P.s.i.		
A-1	0.321	75,700	32,630		
A-2	.322	80,030	33,900		
A-3	.325	83,800	27,730		
Av.	.323	79,850	31,400	21.908	13.738
B-1	.568	80,730	29,820		
B-2	.567	77,430	32,160		
B-3	.568	88,130	32,980		
Av.	.568	82,100	31,650	29.291	18.186
C-1	.812				
C-2	.812				
C-3	.813				
Av.	.812			29.103	19.562

Table 2.--Results of tests on panels of 1/4-inch nominal thickness

Tests of shear specimens					Test of circular panel								
Spec. No.	Load applied	Shear stress	Shear strain	Modulus of rigidity	Gage No.	Distance of gage from center of panel	Load applied	Indicated movement	Shear stress: From test data	Shear stress: From test data: Adjusted value	Shear stress: Computed by formula	K: From adjusted test data	K: Computed by formula
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Pounds	P.s.i.	In./in.	P.s.i.		Inches	Pounds	In./in.	P.s.i.	P.s.i.	P.s.i.		
					Panel A-1 (Strains measured in LT direction)								
					1	1.25	140	0.001622	122.78	(71.46)	60.72	0.937	0.796
A1-A1	2,000	166.2	0.00233	71,400	2	1.50	140	.001228	92.96	(54.10)	50.84	.709	.667
A1-A2	2,000	166.4	.00197	84,500	3	1.75	140	.001112	84.18	(48.99)	43.58	.642	.571
A1-A3	2,000	166.4	.00233	71,200	4	2.00	140	.001081	81.83	(47.62)	38.13	.624	.500
					5	3.00	140	.000718	54.35	(31.63)	25.42	.415	.333
Av.		166.3	.00221	75,700	6	4.00	140	.000541	40.95	(23.83)	19.07	.312	.250
					7	5.00	140	.000541	40.95	(23.83)	15.25	.312	.200
					8	6.00	140	.000208	15.75	(9.17)	12.71	.120	.167
					9	7.00	140	.000394	29.83	(17.36)	10.90	.228	.143
					Panel A-1 (Strains measured in LR direction)								
					1	1.25	140	.002749	89.70	(58.30)	58.79	.764	.771
A1-B1	1,000	83.7	.00258	32,400	2	1.50	140	.002610	85.16	(55.35)	50.79	.726	.666
A1-B2	1,000	83.2	.00246	33,800	3	1.75	140	.001884	61.48	(39.96)	43.58	.524	.571
A1-B3	1,000	83.2	.00262	31,700	4	2.00	140	.001405	45.84	(29.80)	38.13	.391	.500
					5	3.00	140	.001436	46.86	(30.46)	25.42	.399	.333
Av.		83.3	.00255	32,630	6	4.00	140	.001081	35.27	(22.92)	19.07	.300	.250
					7	5.00	140	.000695	22.68	(14.74)	15.25	.193	.200
					8	6.00	140	.000463	15.11	(9.82)	12.71	.129	.167
					9	7.00	140	.000440	14.36	(9.33)	10.90	.122	.143
					Panel A-2 (Strains measured in LT direction)								
					1	1.25	140	.001622	129.81	(75.55)	60.72	.991	.796
					2	1.50	140	.001622	129.81	(75.55)	50.84	.991	.667
A2-A1	2,000	166.4	.00179	93,000	3	1.75	140	.000950	76.03	(44.25)	43.58	.580	.571
A2-A2	2,000	166.4	.00194	85,800	4	2.00	140	.001274	101.96	(59.34)	38.13	.778	.500
A2-A3	2,000	167.2	.00273	61,300	5	3.00	140	.000595	47.62	(27.71)	25.42	.363	.333
					6	4.00	140	.000788	63.06	(36.70)	19.07	.481	.250
Av.		166.7	.00215	80,030	7	5.00	140	.000541	43.30	(25.20)	15.25	.330	.200
					8	6.00	140	.000541	43.30	(25.20)	12.71	.330	.167
					9	7.00	140	.000324	25.93	(15.09)	10.90	.198	.143

(Sheet 1 of 2)

Table 2.--Results of tests on panels of 1/4-inch nominal thickness (Continued)

Spec. No.	Load applied	Shear stress	Shear strain	Modulus of rigidity	Gage No.	Distance of gage from center of panel	Load applied	Indicated movement	Shear stress: From test data	Shear stress: From test data: Adjusted value	Shear stress: Computed by formula	K: From adjusted test data	K: Computed by formula
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Tests of shear specimens					Test of circular panel								
	Pounds	P.s.i.	In./in.	P.s.i.		Inches	Pounds	In./in.	P.s.i.	P.s.i.	P.s.i.		
					Panel A-2 (Strains measured in LR direction)								
					1	1.25	140	0.002880	97.63	(63.46)	58.79	0.832	0.771
A2-B1	1,000	83.2	0.00223	37,300	2	1.50	140	.002046	69.36	(45.08)	50.79	.591	.666
A2-B2	1,000	83.5	.00265	31,400	3	1.75	140	.002031	68.85	(44.75)	43.58	.587	.571
A2-B3	1,000	83.3	.00252	33,000	4	2.00	140	.001676	56.82	(36.93)	38.13	.484	.500
					5	3.00	140	.001421	48.17	(31.31)	25.42	.410	.333
Av.		83.3	.00247	33,900	6	4.00	140	.001081	36.65	(23.82)	19.07	.312	.250
					7	5.00	140	.000780	26.44	(17.19)	15.25	.225	.200
					8	6.00	140	.000548	18.58	(12.08)	12.71	.158	.167
					9	7.00	140	.000347	11.76	(7.64)	10.90	.100	.143
					Panel A-3 (Strains measured in LT direction)								
					1	1.25	140	.001290	108.10	(62.91)	60.72	.825	.796
A3-A1	2,000	166.5	.00192	86,800	2	1.50	140	.000865	72.49	(42.19)	50.84	.553	.667
A3-A2	2,000	166.7	.00194	85,800	3	1.75	140	.001305	109.36	(63.65)	43.58	.835	.571
A3-A3	2,000	166.4	.00211	78,800	4	2.00	140	.000355	29.75	(17.31)	38.13	.227	.500
					5	3.00	140	.000579	48.52	(28.24)	25.42	.370	.333
Av.		166.5	.00199	83,800	6	4.00	140	.000633	53.04	(30.87)	19.07	.405	.250
					7	5.00	140	.000541	45.34	(26.39)	15.25	.346	.200
					8	6.00	140	.000371	31.09	(18.09)	12.71	.237	.167
					9	7.00	140	.000347	29.08	(16.92)	10.90	.222	.143
					Panel A-3 (Strains measured in LR direction)								
					1	1.25	140	.002100	58.23	(37.85)	58.79	.496	.771
					2	1.50	140	.002448	67.88	(44.12)	50.79	.578	.666
A3-B1	1,000	83.3	.00276	30,200	3	1.75	140	.001892	52.46	(34.10)	43.58	.447	.571
A3-B2	1,000	83.3	.00321	26,000	4	2.00	140	.001421	39.40	(25.61)	38.13	.336	.500
A3-B3	1,000	83.3	.00310	27,000	5	3.00	140	.001027	28.48	(18.51)	25.42	.243	.333
					6	4.00	140	.000641	17.78	(11.56)	19.07	.152	.250
Av.		83.3	.00302	27,730	7	5.00	140	.000633	17.55	(11.41)	15.25	.150	.200
					8	6.00	140	.000425	11.78	(7.66)	12.71	.100	.167
					9	7.00	140	.000494	13.70	(8.90)	10.90	.117	.143

(Sheet 2 of 2)

Table 3.--Results of tests on panels of 1/2-inch nominal thickness

Tests of shear specimens					Test of circular panel								
Spec. No.	Load applied	Shear stress	Shear strain	Modulus of rigidity	Gage No.	Distance of gage from center of panel	Load applied	Indicated movement	Shear stress: From test data	Shear stress: From test data: Adjusted value	Shear stress: Computed by formula	K: From adjusted test data	K: Computed by formula
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Pounds	P.s.i.	In./in.	P.s.i.		Inches	Pounds	In./in.	P.s.i.	P.s.i.	P.s.i.		
						Panel B-1 (Strains measured in LT direction)							
					1	1.25	200	0.001270	102.53	(59.67)	47.42	1.006	0.799
B1-A1	2,000	166.7	0.00271	61,600	2	1.50	200	.001158	93.48	(54.40)	39.54	.917	.667
B1-A2	2,000	166.5	.00170	97,700	3	1.75	200	.000885	71.45	(41.58)	33.90	.701	.571
B1-A3	2,000	166.7	.00201	82,900	4	2.00	200	.000829	66.92	(38.95)	29.66	.657	.500
					5	3.00	200	.000567	45.77	(26.64)	19.77	.449	.333
Av.		166.6	.00214	80,730	6	4.00	200	.000496	40.04	(23.30)	14.83	.393	.250
					7	5.00	200	.000349	28.17	(16.39)	11.86	.276	.200
					8	6.00	200	.000238	19.21	(11.18)	9.89	.188	.167
					9	7.00	200	.000206	16.63	(9.68)	8.47	.163	.143
						Panel B-1 (Strains measured in LR direction)							
					1	1.25	200	.002176	64.89	(42.18)	46.83	.711	.790
B1-B1	1,200	100.0	.00333	30,000	2	1.50	200	.001718	51.23	(33.30)	39.54	.562	.667
B1-B2	1,200	99.8	.00342	29,200	3	1.75	200	.001381	41.18	(26.77)	33.90	.451	.571
B1-B3	1,200	100.0	.00331	30,250	4	2.00	200	.001100	32.80	(21.32)	29.66	.359	.500
					5	3.00	200	.000861	25.68	(16.69)	19.77	.281	.333
Av.		99.9	.00335	29,820	6	4.00	200	.000861	25.68	(16.69)	14.83	.281	.250
					7	5.00	200	.000520	15.51	(10.08)	11.86	.170	.200
					8	6.00	200	.000436	13.02	(8.46)	9.89	.143	.167
					9	7.00	200	.000290	8.65	(5.62)	8.47	.095	.143
						Panel B-2 (Strains measured in LT direction)							
					1	1.25	200	.000925	71.62	(41.68)	47.42	.703	
B2-A1	2,000	166.1	.00235	70,700	2	1.50	200	.000948	73.40	(42.72)	39.54	.720	
B2-A2	2,000	168.0	.00229	73,400	3	1.75	200	.001087	84.17	(48.99)	33.90	.826	
B2-A3	2,000	166.2	.00188	88,200	4	2.00	200	.000595	46.07	(26.81)	29.66	.452	
					5	3.00	200	.000409	31.67	(18.43)	19.77	.311	
Av.		166.8	.00217	77,430	6	4.00	200	.000329	25.47	(14.82)	14.83	.250	
					7	5.00	200	.000306	23.69	(13.79)	11.86	.233	
					8	6.00	200	.000270	20.91	(12.17)	9.89	.205	
					9	7.00	200	.000194	15.02	(8.74)	8.47	.147	

(Sheet 1 of 2)

Table 3.--Results of tests on panels of 1/2-inch nominal thickness (Continued)

Spec. No.	Load applied	Shear stress	Shear strain	Modulus of rigidity	Gage No.	Distance of gage from center of panel	Load applied	Indicated movement	Shear stress: From test data	Shear stress: From test data: Adjusted value	Shear stress: Computed by formula	K: From adjusted test data	K: Computed by formula
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Pounds	P.s.i.	In./in.	P.s.i.		Inches	Pounds	In./in.	P.s.i.	P.s.i.	P.s.i.		
						Panel B-2 (Strains measured in LR direction)							
					1	1.25	200	0.001874	60.27	(39.18)	46.83	0.660	
B2-B1	1,200	99.9	0.00298	33,550	2	1.50	200	.001532	49.27	(32.02)	39.54	.540	
B2-B2	1,200	100.0	.00283	35,450	3	1.75	200	.001298	41.74	(27.13)	33.90	.457	
B2-B3	1,200	99.9	.00363	27,480	4	2.00	200	.001600	51.40	(33.41)	29.66	.563	
					5	3.00	200	.000810	26.05	(16.93)	19.77	.285	
Av.		99.9	.00315	32,160	6	4.00	200	.000710	22.83	(14.84)	14.83	.250	
					7	5.00	200	.000488	15.69	(10.20)	11.86	.172	
					8	6.00	200	.000349	11.22	(7.29)	9.89	.123	
					9	7.00	200	.000246	7.91	(5.14)	8.47	.087	
						Panel B-3 (Strains measured in LT direction)							
					1	1.25	200	.001119	98.62	(57.40)	47.42	.968	
B3-A1	2,000	166.5	.00164	101,700	2	1.50	200	.000568	50.06	(29.13)	39.54	.491	
B3-A2	2,000	167.5	.00198	84,600	3	1.75	200	.000817	72.00	(41.90)	33.90	.706	
B3-A3	2,000	168.0	.00215	78,100	4	2.00	200	.000793	69.89	(40.68)	29.66	.686	
					5	3.00	200	.000508	44.77	(26.06)	19.77	.439	
Av.		167.3	.00192	88,130	6	4.00	200	.000455	40.10	(23.34)	14.83	.393	
					7	5.00	200	.000405	35.69	(20.77)	11.86	.350	
					8	6.00	200	.000207	18.24	(10.62)	9.89	.179	
					9	7.00	200	.000207	18.24	(10.62)	8.47	.179	
						Panel B-3 (Strains measured in LR direction)							
					1	1.25	200	.001833	60.45	(39.29)	46.83	.662	
B3-B1	1,200	100.0	.00272	36,700	2	1.50	200	.001520	50.13	(32.58)	39.54	.549	
B3-B2	1,200	99.7	.00356	28,030	3	1.75	200	.001440	47.49	(30.87)	33.90	.520	
B3-B3	1,200	100.5	.00295	34,200	4	2.00	200	.001132	37.33	(24.26)	29.66	.409	
					5	3.00	200	.000782	25.79	(16.76)	19.77	.283	
Av.		100.1	.00308	32,980	6	4.00	200	.000595	19.62	(12.75)	14.83	.215	
					7	5.00	200	.000580	19.13	(12.43)	11.86	.210	
					8	6.00	200	.000409	13.49	(8.77)	9.89	.148	
					9	7.00	200	.000286	9.43	(6.13)	8.47	.103	

(Sheet 2 of 2)

Table 4.--Results of tests on panels of 3/4-inch nominal thickness

Spec. No.	Load applied	Shear stress	Shear strain	Modulus of rigidity	Gage No.	Distance of gage from center of panel	Load applied	Indicated movement	Shear stress: From test data	Shear stress: Adjusted value	Shear stress: Computed by formula	K: From adjusted test data	K: Computed by formula
Tests of shear specimens[1]					Test of circular panel								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Pounds	P.s.i.	In./in.	P.s.i.		Inches	Pounds	In./in.	P.s.i.	P.s.i.	P.s.i.		
Panel C-1 (Strains measured in LT direction)													
					1	1.25	300	0.001005	82.51	(48.02)	48.91	0.785	0.800
					2	1.50	300	.000930	76.35	(44.44)	40.79	.726	.667
					3	1.75	300	.000829	68.06	(39.61)	34.96	.647	.571
					4	2.00	300	.000684	56.15	(32.68)	30.59	.534	.500
					5	3.00	300	.000602	49.42	(28.76)	20.39	.470	.333
					6	4.00	300	.000420	34.48	(20.07)	15.30	.328	.250
					7	5.00	300	.000286	23.48	(13.67)	12.24	.223	.200
Av.	2,000	166.9	0.00208	82,100	8	6.00	300	.000163	13.38	(7.79)	10.20	.127	.167
					9	7.00	300	.000192	15.76	(9.17)	8.74	.150	.143
Panel C-1 (Strains measured in LR direction)													
					1	1.25	300	.001612	51.02	(33.16)	48.53	.542	.796
					2	1.50	300	.001636	51.78	(33.66)	40.78	.550	.667
					3	1.75	300	.001433	45.36	(29.48)	34.96	.482	.571
					4	2.00	300	.001163	36.81	(23.93)	30.59	.391	.500
					5	3.00	300	.001000	31.65	(20.57)	20.39	.336	.333
					6	4.00	300	.000829	26.24	(17.06)	15.30	.279	.250
					7	5.00	300	.000583	18.45	(11.99)	12.24	.196	.200
Av.	1,200	100.0	.00319	31,650	8	6.00	300	.000438	13.86	(9.01)	10.20	.147	.167
					9	7.00	300	.000318	10.07	(6.55)	8.74	.107	.143
Panel C-2 (Strains measured in LT direction)													
					1	1.25	300	.001155	94.82	(55.19)	48.91	.902	.800
					2	1.50	300	.000711	58.37	(33.97)	40.79	.555	.667
					3	1.75	300	.001265	103.85	(60.44)	34.96	.988	.571
					4	2.00	300	.000396	32.51	(18.92)	30.59	.309	.500
					5	3.00	300	.000567	46.55	(27.09)	20.39	.443	.333
					6	4.00	300	.000422	34.64	(20.16)	15.30	.330	.250
					7	5.00	300	.000305	25.04	(14.57)	12.24	.238	.200
Av.	2,000	166.9	.00208	82,100	8	6.00	300	.000160	13.14	(7.65)	10.20	.125	.167
					9	7.00	300	.000241	19.79	(11.52)	8.74	.188	.143

(Sheet 1 of 2)

Table 4.--Results of tests on panels of 3/4-inch nominal thickness (Continued)

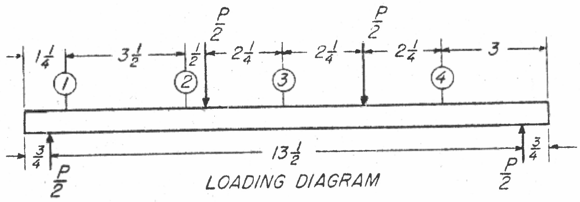
Tests of shear specimens[1]					Test of circular panel								
Spec. No.	Load applied	Shear stress	Shear strain	Modulus of rigidity	Gage No.	Distance of gage from center of panel	Load applied	Indicated movement	Shear stress: From test data	Shear stress: From test data: Adjusted value	Shear stress: Computed by formula	K: From adjusted test data	K: Computed by formula
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Pounds	P.s.i.	In./in.	P.s.i.		Inches	Pounds	In./in.	P.s.i.	P.s.i.	P.s.i.		
						Panel C-2 (Strains measured in LR direction)							
					1	1.25	300	0.001917	60.68	(39.44)	48.53	0.645	0.796
					2	1.50	300	.001460	46.21	(30.04)	40.78	.491	.667
					3	1.75	300	.001136	35.96	(23.37)	34.96	.382	.571
					4	2.00	300	.001096	34.69	(22.55)	30.59	.369	.500
					5	3.00	300	.000829	26.24	(17.06)	20.39	.279	.333
					6	4.00	300	.000409	12.95	(8.42)	15.30	.138	.250
					7	5.00	300	.000476	15.07	(9.80)	12.24	.160	.200
Av.	1,200	100.0	0.00319	31,650	8	6.00	300	.000324	10.26	(6.67)	10.20	.109	.167
					9	7.00	300	.000302	9.56	(6.21)	8.74	.102	.143
						Panel C-3 (Strains measured in LT direction)							
					1	1.25	300	.001080	88.66	(51.60)	48.91	.843	.800
					2	1.50	300	.000781	64.12	(37.32)	40.79	.610	.667
					3	1.75	300	.000703	57.71	(33.59)	34.96	.549	.571
					4	2.00	300	.000858	70.44	(41.00)	30.59	.670	.500
					5	3.00	300	.000591	48.52	(28.24)	20.39	.462	.333
					6	4.00	300	.000853	70.03	(40.76)	15.30	.666	.250
					7	5.00	300	.000326	26.76	(15.57)	12.24	.254	.200
Av.	2,000	166.9	.00208	82,100	8	6.00	300	.000267	21.92	(12.76)	10.20	.209	.167
					9	7.00	300	.000198	16.26	(9.46)	8.74	.155	.143
						Panel C-3 (Strains measured in LR direction)							
					1	1.25	300	.002134	67.55	(43.91)	48.53	.718	.796
					2	1.50	300	.001270	40.20	(26.13)	40.78	.427	.667
					3	1.75	300	.001016	32.16	(20.90)	34.96	.342	.571
					4	2.00	300	.001233	39.03	(25.37)	30.59	.415	.500
					5	3.00	300	.000674	21.33	(13.86)	20.39	.227	.333
					6	4.00	300	.000652	20.64	(13.42)	15.30	.219	.250
					7	5.00	300	.000543	17.19	(11.17)	12.24	.183	.200
Av.	1,200	100.0	.00319	31,650	8	6.00	300	.000465	14.72	(9.57)	10.20	.156	.167
					9	7.00	300	.000321	10.16	(6.60)	8.74	.108	.143

[1] Based on average values obtained in tests on panels of 1/2-inch nominal thickness (Table 3).

Table 5.--Distribution of facing strains of sandwich panels at an applied center load of 100 pounds

Orientation of strain gage with respect to ribbon-direction of core	Computed facing strains at edge of insert r = 1"	Measured radial facing strains at r = 1.25"	r = 1.50"	r = 2.00"	r = 3.00"
(1)	(2)	(3)	(4)	(5)	(6)
	In./in.	In./in.	In./in.	In./in.	In./in.
		Panel A-3 (Average thickness = 0.261 inch)			
LT	0.000530	0.000194	0.000198	0.000116	0.000074
L 45°	....	.000180	.000151	.000107	.000063
LR	.000652	.000171	.000149	.000093	.000060
		Panel B-2 (Average thickness = 0.504 inch)			
LT	.000326	.000103	.000089	.000072	.000039
L 45°	....	.000122	.000089	.000072	.000042
LR	.000421	.000100	.000077	.000057	.000040
		Panel C-2 (Average thickness = 0.748 inch)			
LT	.000202	.000080	.000066	.000055	.000031
L 45°	....	.000063	.000043	.000043	.000023
LR	.000270	.000051	.000044	.000030	.000025

Table 6.--Details of loading and shear strains in core of rectangular sandwich strips at an applied load of 100 pounds.



THEORETICAL SHEAR DIAGRAM

Specimen No.	Orientation of core[1]	Deflection at center of span	Shear strain in core at location 1	2	3	4	Modulus of rigidity of core material
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Inch	In./in.	In./in.	In./in.	In./in.	P.s.i.
			Specimens with 0.032 inch thick aluminum faces				
AB 2	R	0.054	0.00212	0.00268	0.00000	0.00254	34,120
AB 3	R	.053	.00223	.00355	.00000	.00256	27,760
BB 2	R	.052	.00218	.00235	.00037	.00203	31,500
BB 3	R	.054	.00193	.00218	.00042	.00223	27,700
Av.		.053	.00212	.00269	.00020	.00234	30,270
CB 2	T	.049	.00108	.00153	.00000	.00120	68,100
CB 3	T	.049	.00127	.00106	.00019	.00122	65,200
DB 2	T	.048	.00091	.00062	.00033	.00113	82,600
DB 3	T	.049	.00135	.00117	.00040	.00121	62,800
Av.		.049	.00115	.00110	.00023	.00119	69,675
			Specimens with 0.012 inch thick aluminum faces				
A2 B2	R	.125	.00310	.00262	.00024	.00235	
A2 B3	R	.121	.00266	.00227	.00000	.00227	
Av.		.123	.00288	.00244	.00012	.00231	
A1 B2	T	.117	.00147	.00311	.00000	.00139	
A1 B3	T	.118	.00181	.00208	.00106	.00177	
Av.		.118	.00164	.00260	.00053	.00158	
			Specimens with 0.064 inch thick aluminum faces				
B2 B2	R	.024	.00155	.00178	.00000	.00178	
B2 B3	R	.024	.00151	.00155	.00031	.00163	
Av.		.024	.00153	.00166	.00016	.00170	
B1 B2	T	.020	.00066	.00078	.00000	.00066	
B1 B3	T	.021	.00077	.00070	.00000	.00085	
Av.		.020	.00072	.00074	.00000	.00076	

[1]In all cases the R or T symbols (Figure 1) indicate the orientation with respect to the long dimension of the bending specimen.

Table 7.--Variation between indicated shear strain and deflection of a rectangular sandwich strip in flexure. A total load of 100 pounds was applied in all cases.

Specimen No.	Facing thickness	Total span	Distance between reaction and load point	Indicated shear strain	Deflections: At center of length of beam	Deflections: Between reaction and load point	Slope of beam at point of measurement (Neutral axis)	Radius of curvature of beam at point of measurement (Neutral axis)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Inch	Inches	Inches	In./in.	Inch	Inch	In./in.	Inches
Al B3	0.012	13.50	4.50	0.00177	0.118	0.059	0.0239	329
Al B3	.012	11.50	3.50	.00177	.067	.031	.0165	432
Al B3	.012	9.50	2.50	.00177	.044	.018	.0137	465
Al B3	.012	7.50	1.50	.00165	.016	.005	.0068	832
Av. of 4[1]	.032	13.50	4.50	.00119	.049	.024	.010	792
Av. of 2[1]	.064	13.50	4.50	.00076	.020	.010	.004	1,941

[1]Averages of pertinent values tabulated in table ~~10~~ 6.

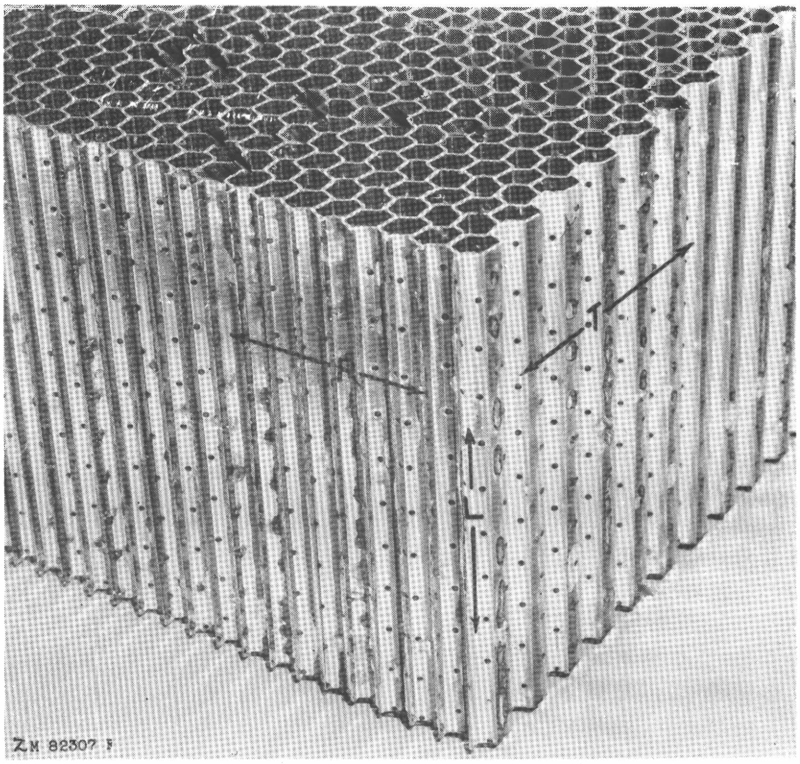


Figure 1.--Section of a block of aluminum honeycomb core material made from perforated aluminum foil. Directional orientation referred to in the text is L (longitudinal), R (radial), and T (tangential). In this study, shear stresses were measured in the LR, LT, and in the longitudinal direction at 45 degrees to the RT planes, referred to as L 45° in the report.

Z M 82307 F

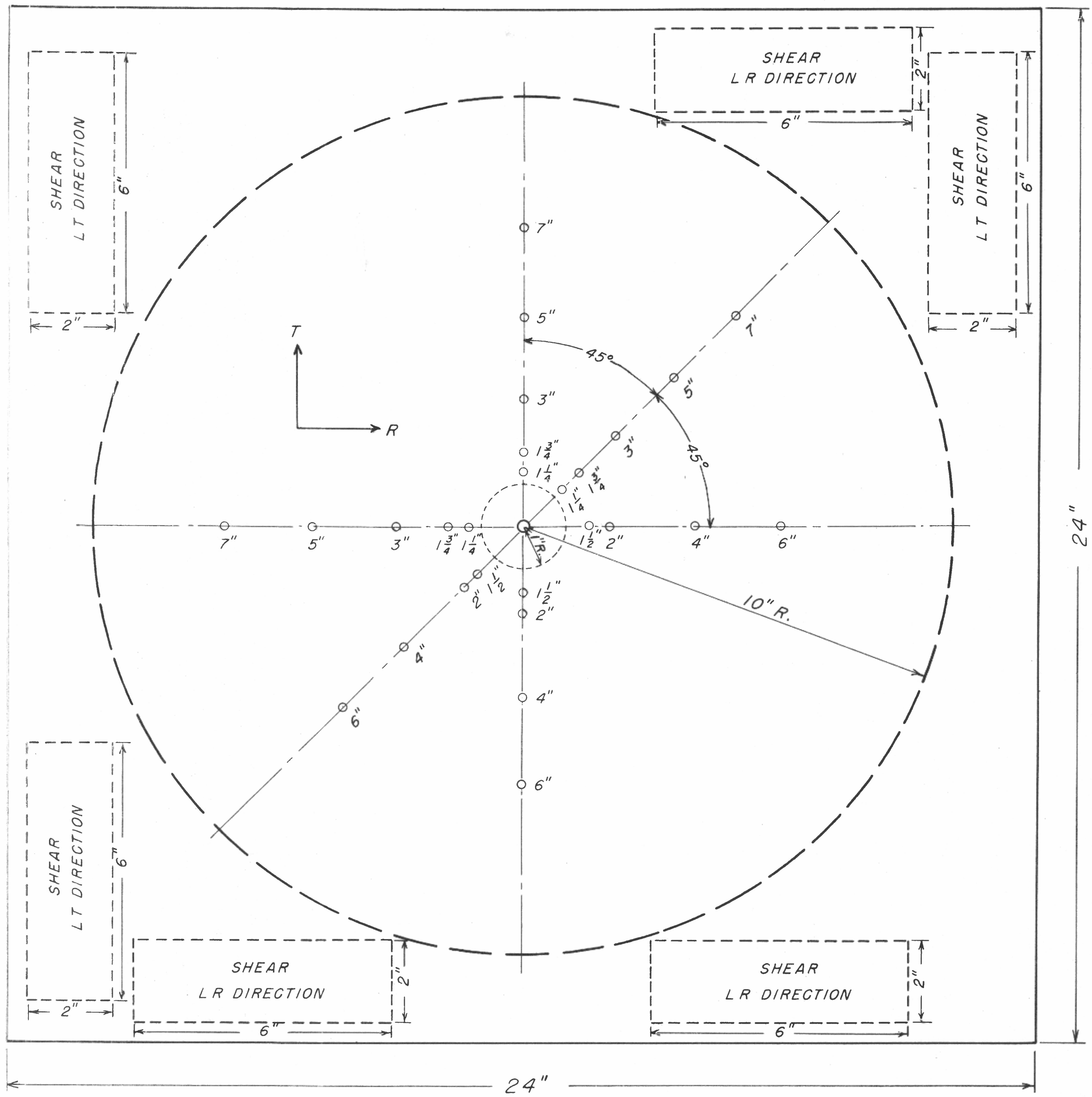


Figure 2.--Details of panel construction showing core orientation, location of insert, location of points at which shear strains were determined, and the distribution of shear specimens cut from each panel.

Z M 106 598

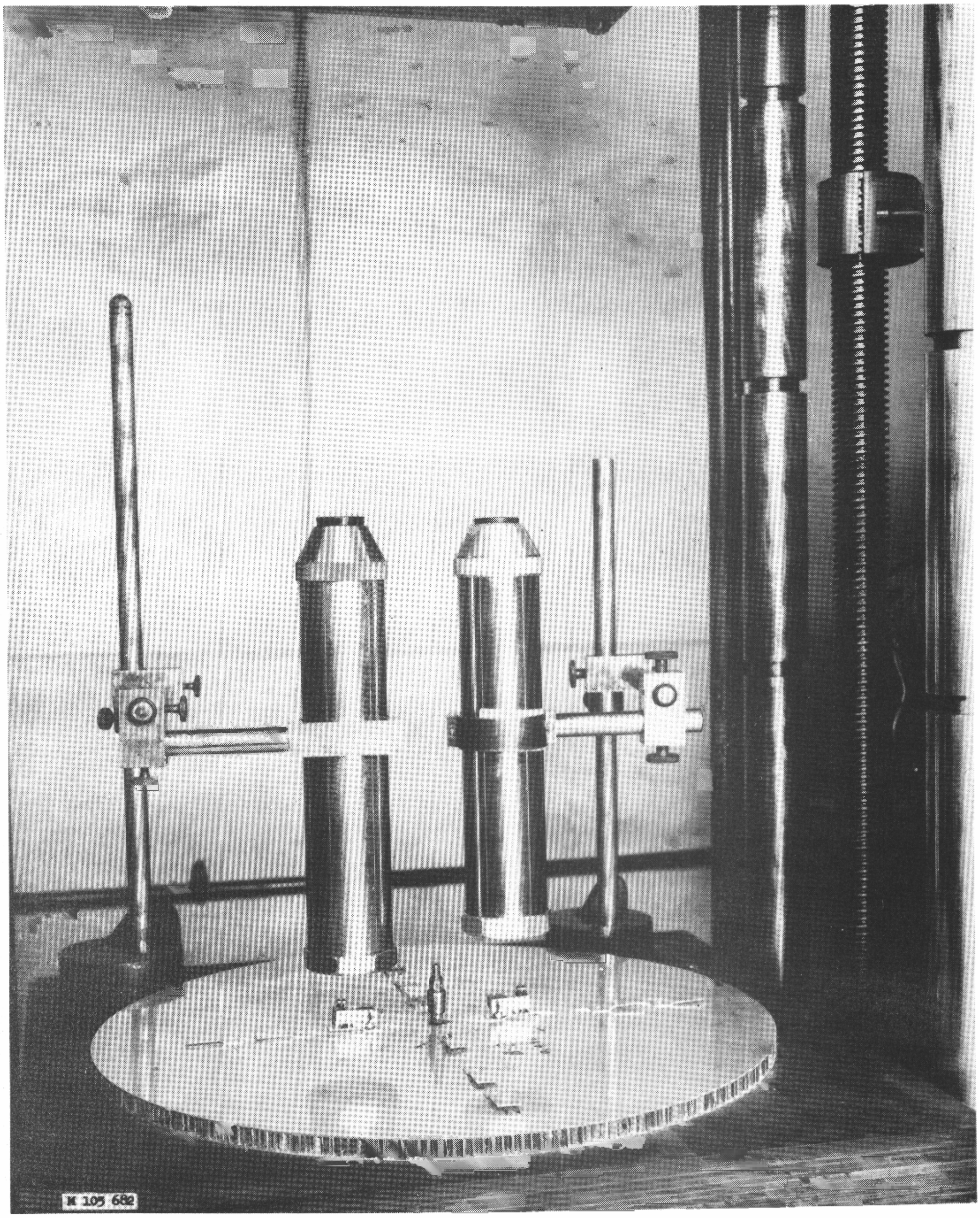


Figure 3.--Circular sandwich panel under test for determination of shear stresses in core. Load is applied to the top of the central insert by applying a tensile load on a flexible cable which terminates in a spherically seated cable clamp which is visible in the photograph. The strain gages, which have a 1-inch gage length, are set to read the differential movement between the top facing (fixed knife edge on clip) and the bottom facing (movable knife edge resting on protruding bolt attached to bottom facing). Strains were read by means of the autocollimators shown. Readings were taken simultaneously at two points, and the test repeated until readings at all points were obtained.

M 105 682

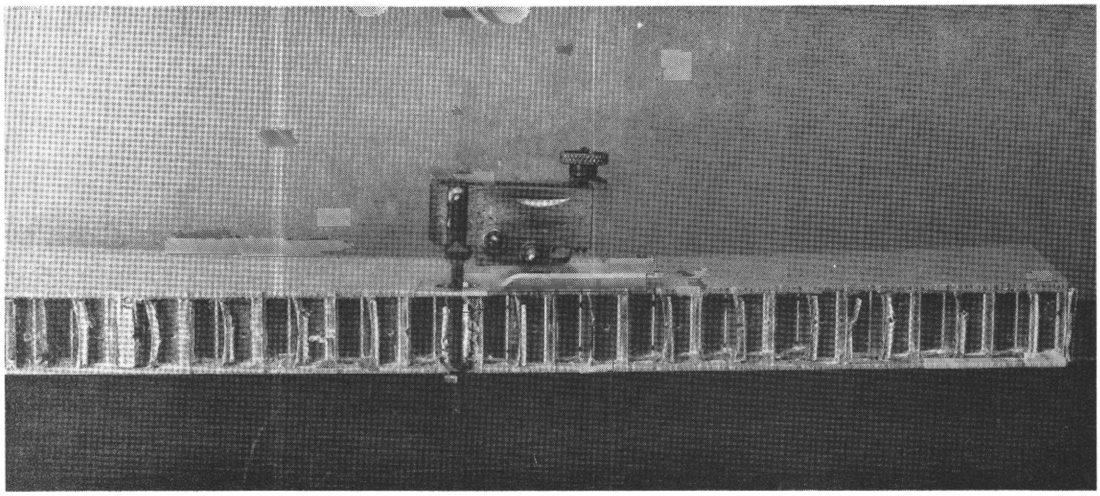


Figure 4.--Cut-away view showing Tuckerman strain gage in position for measuring differential movement of top and bottom facings. Double nuts secure the 1/16-inch diameter bolt to the bottom facing. The aluminum clip supporting the strain gage is glued to the top facing of the panel.

M 105 683

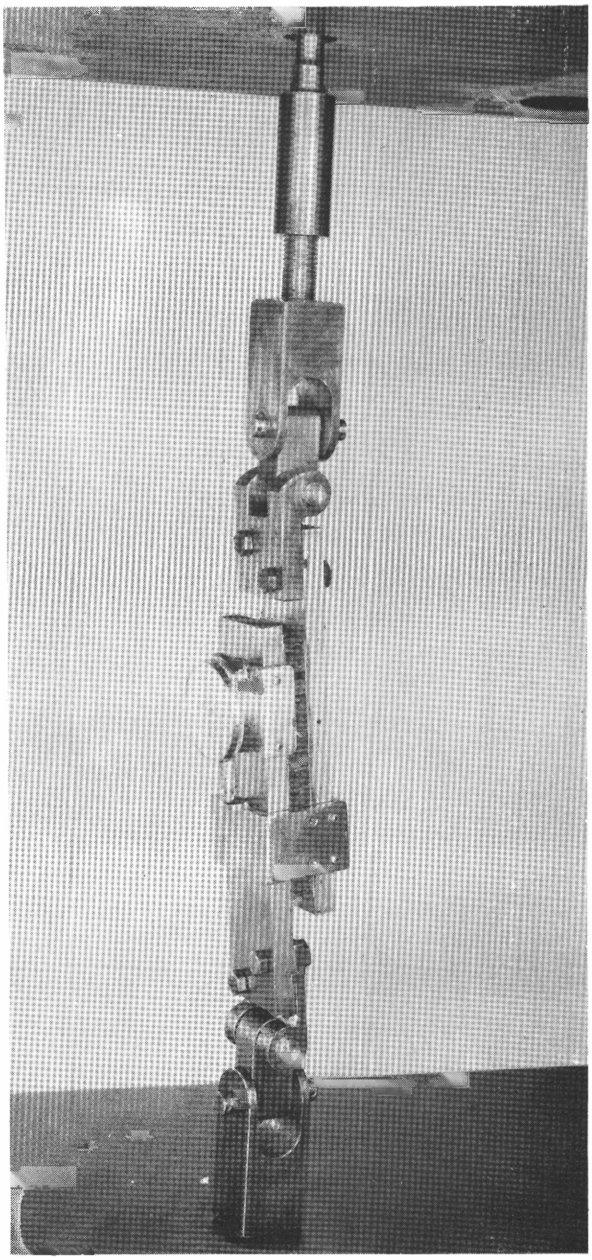


Figure 5.--Apparatus for conducting shear tests of specimens cut from the test panels.

Z M 83718 F

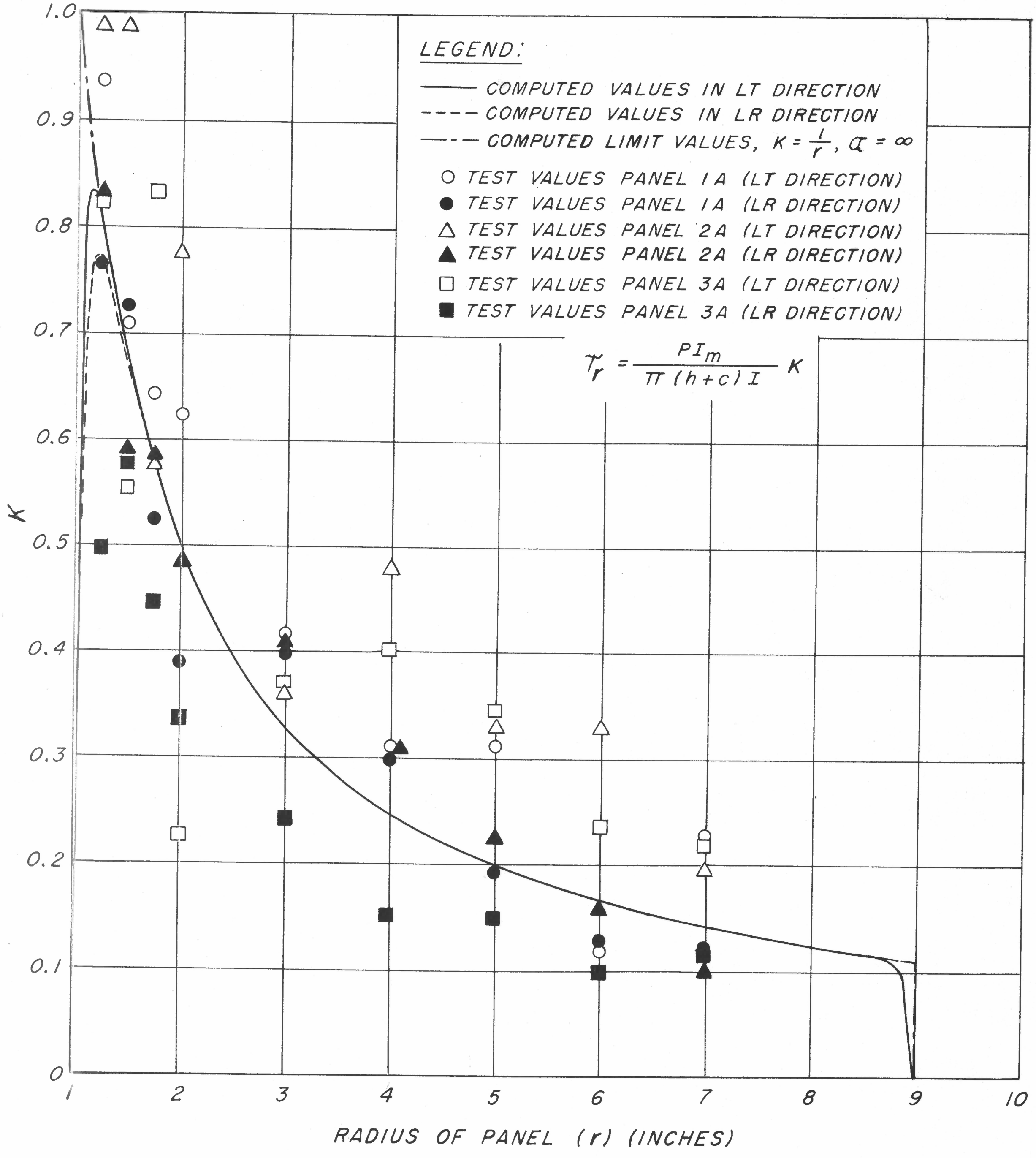


Figure 6.--Computed and observed radial variation in shear stress in the cores of panels of 1/4-inch nominal thickness.

Z M 106 599

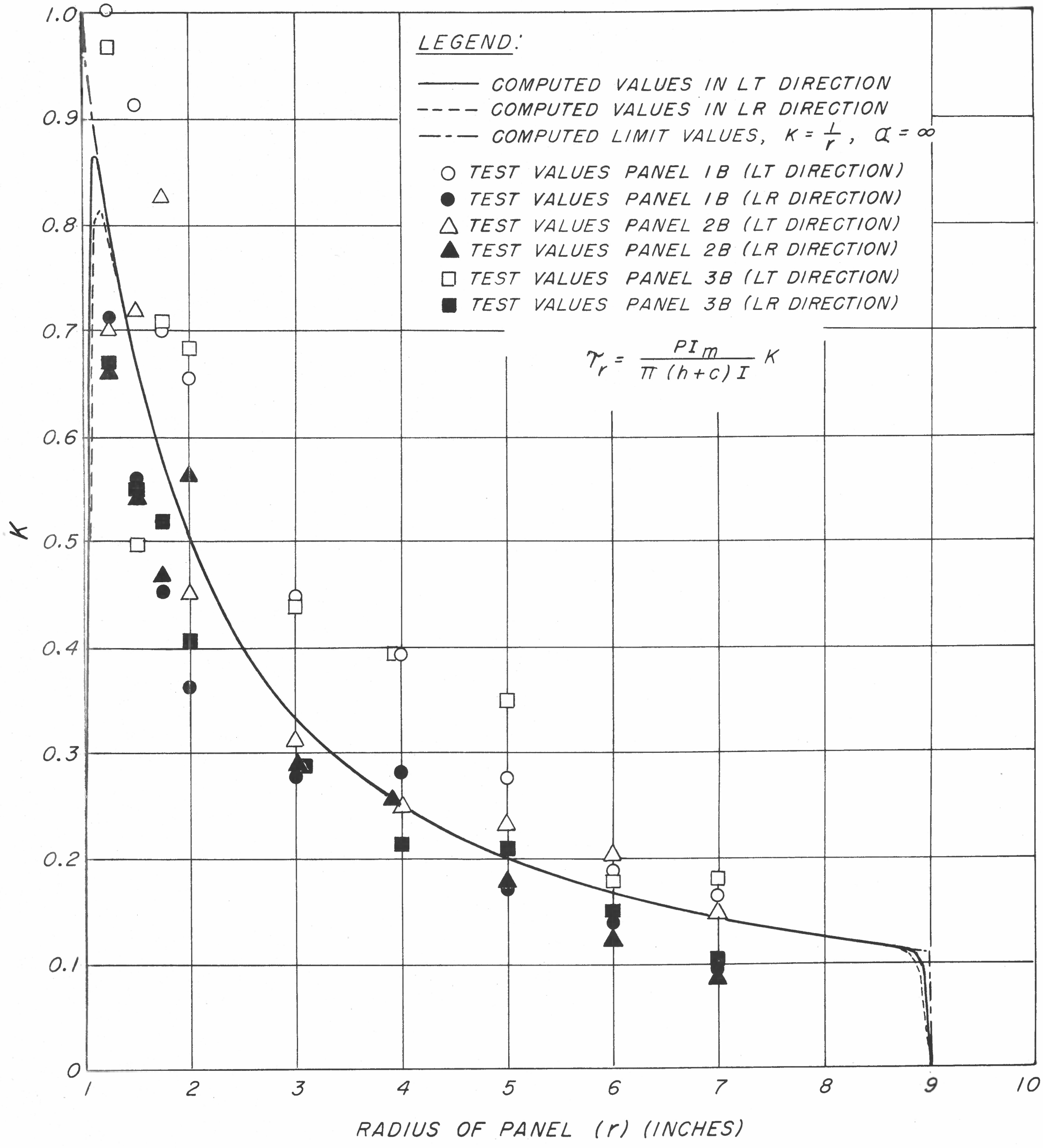


Figure 7.--Computed and observed radial variation in shear stress in the cores of panels of 1/2-inch nominal thickness.

Z M 106 600

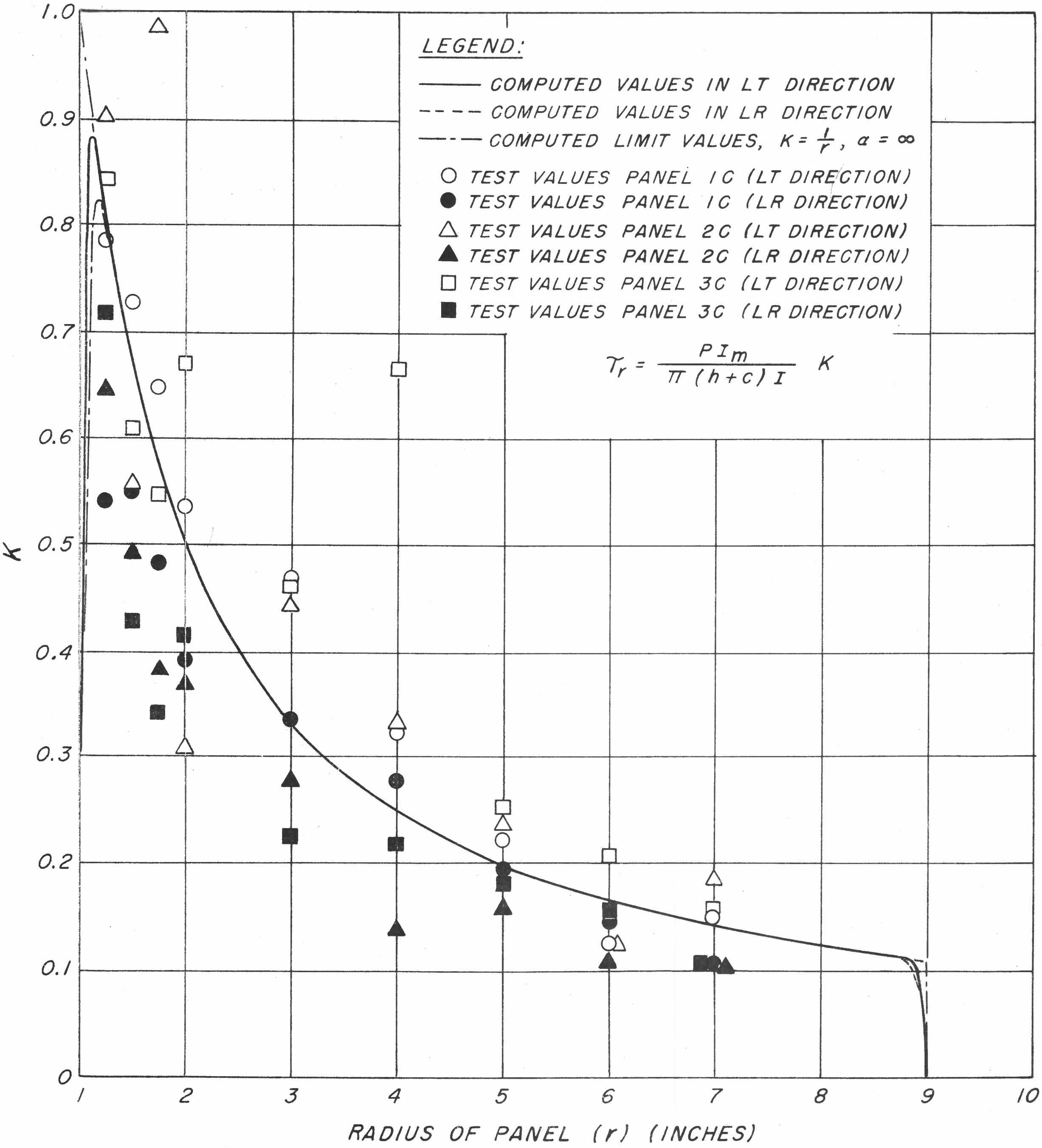


Figure 8.--Computed and observed radial variation in shear stress in the cores of panels of 3/4-inch nominal thickness.

Z M 106 601

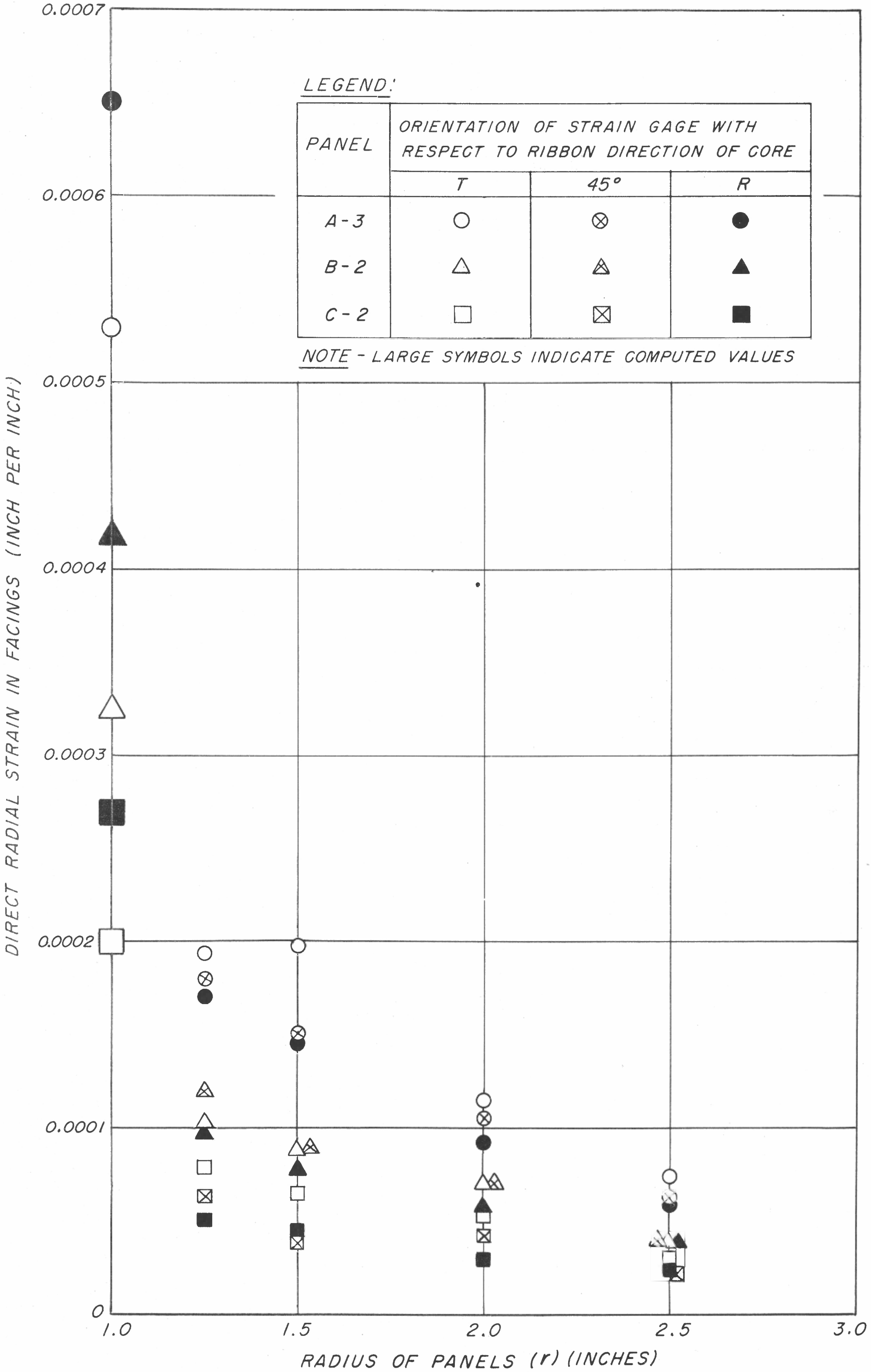


Figure 9.--Relation between computed radial facing strains at the edge of the insert and observed facing strains near the insert.

Z M 106 602

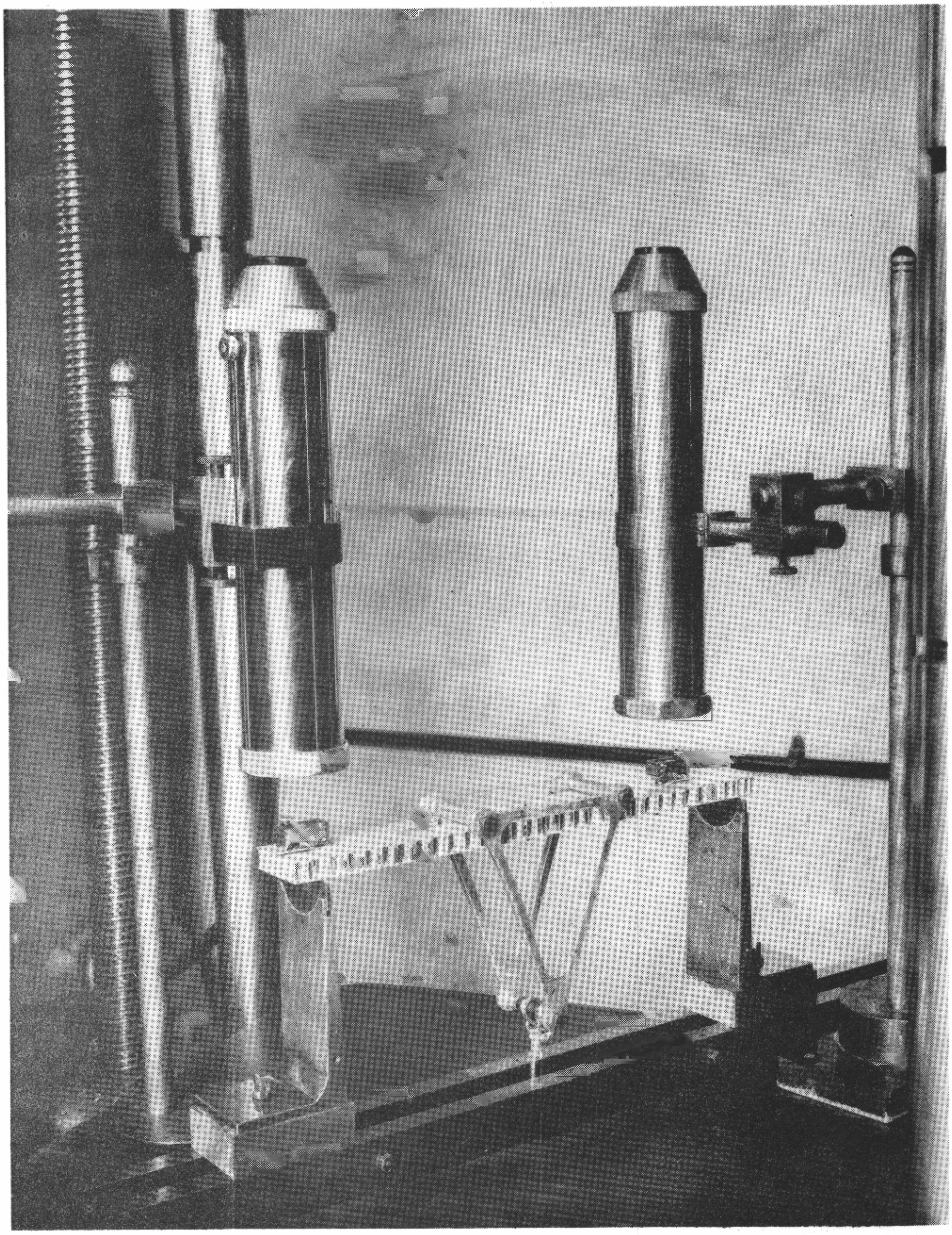


Figure 10.--Method of testing small sandwich beam in bending for determination of shear stresses at various points along the length of the beam.

M 105 736

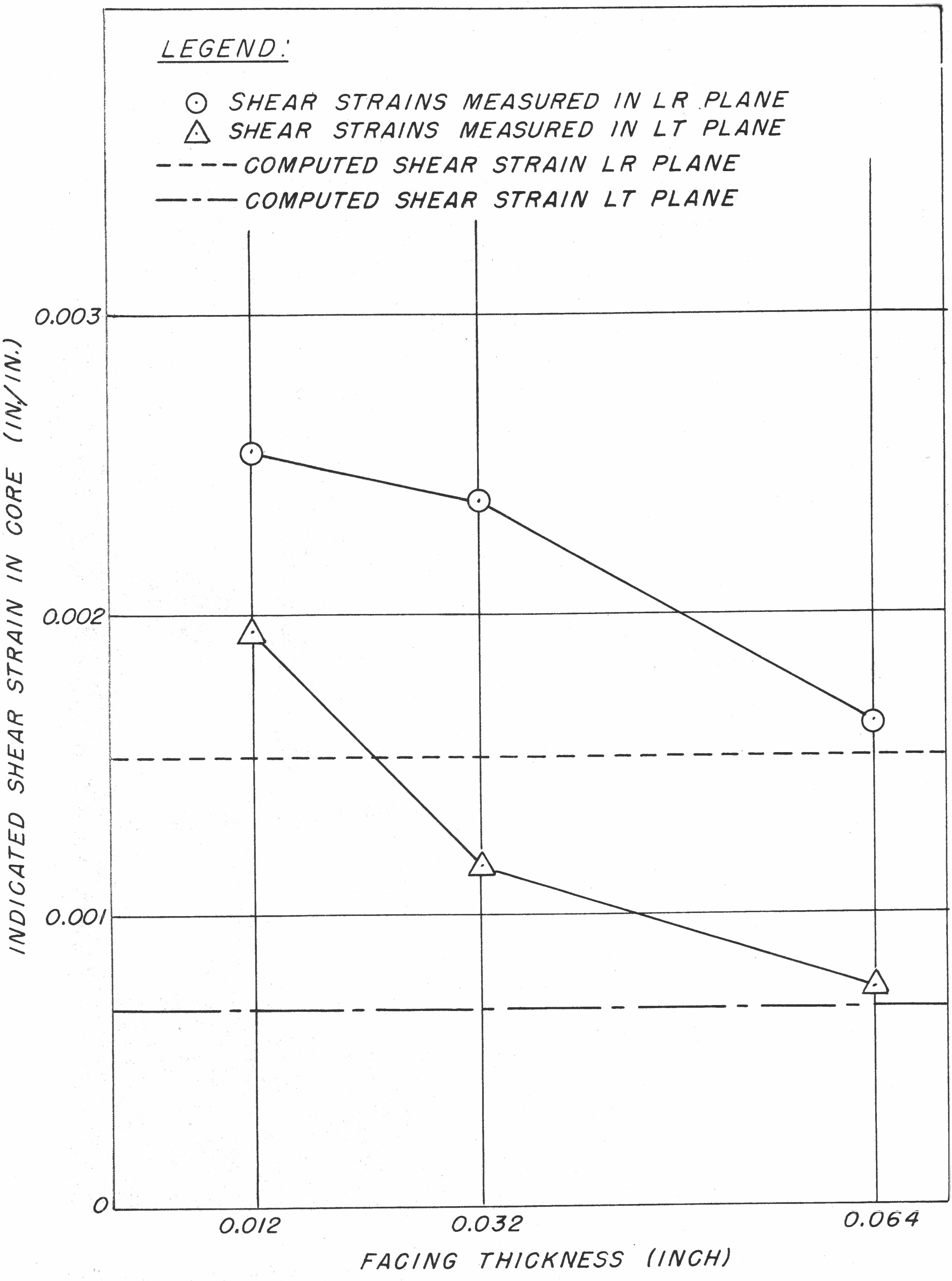


Figure 11.--Relation between the indicated shear strains in the core, and facing thickness of sandwich beams subjected to bending loads. (All specimens were subjected to the same shear stress.)

Z M 106 603

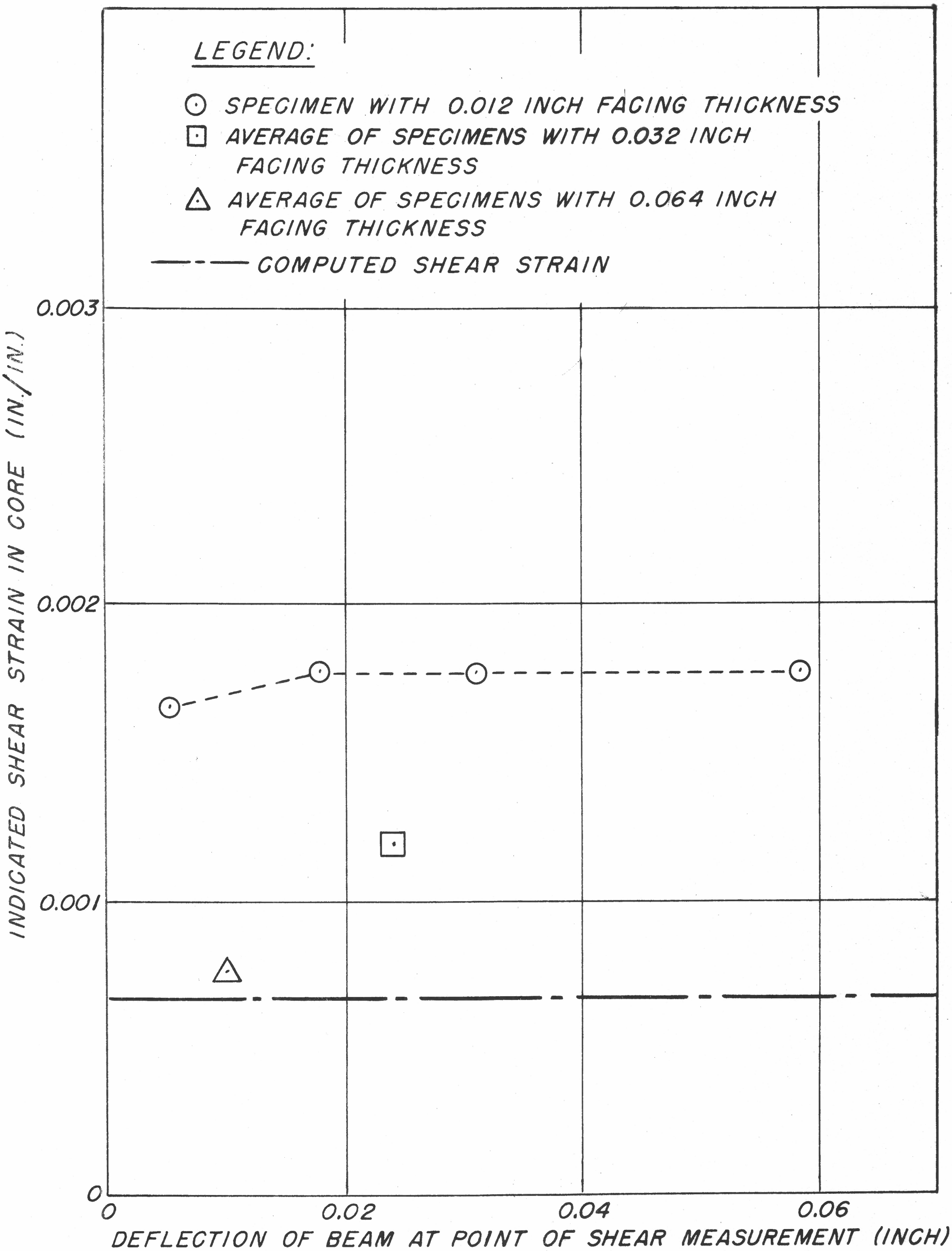


Figure 12.--Relation between indicated shear strains in the core, and deflection of sandwich beams subjected to bending loads. (Deflection measured at the neutral axis at the point of shear measurement.)

Z M 106 604